BULLETIN

OF THE INSTITUTE OF METALS

VOLUME 2 NOVEMBER 1954 PART 15

PERSONAL NOTES

Mr. Z. S. Basinski has left Oxford to take up a post in the Cryogenic Engineering Laboratory, Massachussetts Institute of Technology, Cambridge, Mass.

Mr. H. C. Coe has left The General Electric Co., Ltd., and gone to Australia.

Mr. D. Dew-Hughes has left Birmingham University to become a research associate in the Metallurgy Department, Yale University School of Engineering, New Haven, Conn.

Mr. H. H. Egginton has been appointed Chief Engineer of the Refrigeration Division of The British Thermostat Co., Ltd., Sunbury-on-Thames.

Mr. E. L. Francis has left Rylands Bros., Ltd., to become General Manager of the wire mills of The English Card-Clothing Co., Ltd., Lindley, Huddersfield.

Mr. C. D. Graham has left the Metallurgy Department, Birmingham University, and is now a research associate in the Research Laboratories of The General Electric Co., Schenectady, N.Y.

Dr. R. Haynes has relinquished his position as Lecturer at Leeds University and is now a Technical Officer with Imperial Chemical Industries, Ltd., Metals Division, Birmingham.

Mr. D. E. C. King is now employed on the research staff of Novanda Mines, Ltd., Canada.

Mr. A. J. Lowmass has resigned his position as Chief Metallurgist of South African Goldware in order to take up an appointment as General Manager of Alloy Industries, Vulcania, Brakpan, Transvaal.

Dr. J. N. Pratt has resigned his I.C.I. Fellowship at Manchester University in order to become a Lecturer in Physical Metallurgy at Birmingham University.

Dr. C. Sykes, Managing Director of Thomas Firth and John Brown, Ltd., has been appointed a member of the Advisory Council for Scientific and Industrial Research.

Dr. K. Tangri has left the Missouri School of Mining and is now undertaking postgraduate research at Pennsylvania State University, State College, Pa.

Mr. S. P. Thompson is now a research metallurgist with British Insulated Callender's Cables, Ltd., Wood Lane, London.

Metallurgical Progress and the Chemical Industry

At University College, Swansea, on Tuesday 30 November, at 6.30 p.m., Dr. Maurice Cook will deliver the second Robert Horne Memorial Lecture of the Society of Chemical Industry on "Metallurgical Progress and the Chemical Industry".

Members of the Institute of Metals are cordially invited to attend the lecture.

OBITUARY

Mr. Frank Mason

Mr. Frank Mason died at Sheffield on 20 August 1954, aged 77. There is a sadness in writing a tribute to one who was so appreciative of the gifts in others and so unconscious of them in himself.

His advice and help were constantly in demand and freely given to all seekers. He was one of these rare people who remain completely unaffected by success, and throughout his long life he retained a very genuine modesty and sincere simplicity which, combined with a shrewd understanding of life, made him a trusted friend. An unambitious and in some ways a diffident man, Frank Mason valued more highly the fruits of friendship than the gains of worldly success.

In 1924 he founded the company known as Stainless Plating, Ltd., and was its Managing Director up to 1944, resigning from the Board only a month before his death. The main activity of the Company was high-class chromium plating, and Mr. Mason claimed that he was the first in the world to undertake this type of plating on a commercial scale.

Before forming this Company, Mr. Mason was for several years on the staff of Mappin and Webb, Ltd., and for a period he gave valuable assistance as a lecturer and demonstrator in the electrodeposition laboratories at Sheffield University.

Mr. Mason was elected to membership of the Institute of Metals in 1910. He served for many years on the committee of the Sheffield Local Section, and was its Chairman from 1938 to 1947, being an ex-officio Member of Council during this period. Throughout his long association with the Section he upheld the prestige of the Institute, and in countless ways he was one of the greatest benefactors the Sheffield Local Section has known. He was also a member of the Institution of Electrical Engineers and of the Electrodepositors' Technical Society (now the Institute of Metal Finishing).

During the whole of his life, Mr. Mason was an ardent supporter of the Church, and he served on most of the committees of Sheffield Cathedral. From 1937 until his death he was a highly esteemed churchwarden, and his sound business judgement was greatly valued, especially on the Cathedral extension schemes.

In Freemasonry Mr. Mason was a Past Master of the Milton Lodge and Founder Member of the Cathedral Lodge. He held the office of Past Provincial Grand Deacon in the Yorkshire West Riding, and was a member of the St. Audrey Arch Chapter, having occupied the chair. He was also Past Provincial Assistant Grand Director of Ceremonies of Yorkshire West Riding in the Chapter.

A. J. MACDOUGALL

DIARY

The Institute

25 and 26 November. General Meeting for the Discussion of Papers. (4 Grosvenor Gardens, London, S.W.1.) For details see the *Bulletin*, 1954, Sept., p. 151.

2 December. "The Thermochemistry of Alloys", by Dr. A. R. Harding. Joint Meeting with the Chemical Engineering Group of the Society of Chemical Industry, the Chemical Society, and the Royal Institute of Chemistry. (University Chemical Department, Woodland Road, Bristol, at 6.30 p.m.)

Local Sections and Associated Societies

16 November. Sheffield Local Section. "Specifications: Friends or Foes?" by S. Barraclough. Joint Meeting with the Sheffield Metallurgical Association. (British Iron and Steel Research Association, Hoyle Street, Sheffield, at 7.0 p.m.)

18 November. Liverpool Metallurgical Society. "The Fracture of Metals", by C. E. Phillips. (Liverpool Engineering Society, 9 The Temple, Dale Street, Liverpool, at 7.0 p.m.)

18 November. North East Metallurgical Society. "Aluminium and Its Alloys as Engineering Materials", by E. Elliott. (Cleveland Scientific and Technical Institution, Middlesbrough, at 7.15 p.m.)

24 November. Manchester Metallurgical Society. "Some Experiences in Industrial Research", by Dr. B. P. Dudding. (Lecture Room of the Central Library, Manchester, at 6.30 p.m.)

24 November. Sheffield Local Section. "High-Temperature Water-Cooling of Open-Hearth Furnaces by Means of Steam-Producing Elements", by F. J. Feltoe and P. M. Moreton. "The Cooling of Large Rolling Mill Drives", by P. M. Moreton. Joint Meeting with the Yorkshire Branch of the Institution of Mechanical Engineers. (University Buildings, St. George's Square, Sheffield, at 6.30 p.m.)

25 November. Birmingham Local Section. "The Working of Metals", by J. G. Wistreich. (James Watt Memorial Institute, Great Charles Street, Birmingham 3, at 6.30 p.m.)

2 December. Birmingham Local Section. Students' Evening. (James Watt Memorial Institute, Great Charles Street, Birmingham 3, at 6.30 p.m.)

7 December. Oxford Local Section. Junior Members' Evening. Discussion on Alloy Constitution; Practical Techniques. (1) Laboratory Furnaces and Temperature Control, opened by A. T. Thomas. (2) High-Temperature Thermal Analysis, opened by (Miss) D. Murray. (3) Design of Arc Furnaces, opened by A. Hellawell. (Cadena Café, Cornmarket Street, Oxford, at 7.0 p.m.)

7 December. South Wales Local Section. "Peacetime Uses of Atomic Energy", by Dr. Alex. B. McIntosh. (Metallurgy Department, University College, Singleton Park, Swansea, at 6.45 p.m.)

8 December. Manchester Metallurgical Society. Discussion on "Mechanical Testing". (The Lecture Room of the Central Library, Manchester, at 6.30 p.m.)

13 December. Scottish Local Section. "Casting, Fabrication, and Testing". The names of the speakers, who will be members of the Section, will be announced later. (Institution of Engineers and Shipbuilders in Scotland, 39 Elmbank Crescent, Glasgow, C.2, at 6.30 p.m.)

16 December. Liverpool Metallurgical Society. "Protective Atmospheres for the Heat-Treatment of Steels", by Dr. Ivor Jenkins. (Liverpool Engineering Society, 9 The Temple, Dale Street, Liverpool at 7.0 p.m.)

16 December. London Local Section. "Melting and Casting under Reduced Pressure", by Dr. H. H. Scholefield. (4 Grosvenor Gardens, London, S.W.1, at 6.30 p.m.)

Other Societies

9 November. Institute of British Foundrymen, Slough Section. "Propeller Manufacture", by J. M. Langham. (Lecture Theatre of High Duty Alloys, Ltd., Slough, at 7.30 p.m.)

11 November. Institute of British Foundrymen, Beds./Herts. Section. "Patterns, with Special Reference to Pressure-Cast Aluminium Plate", by B. Perry. (The Small Assembly Room, Town Hall, Luton, at 7.30 p.m.)

11 November. Institute of British Foundrymen, Southampton Section. "Solidification of Metals", by A. Prince. (Technical College, St. Mary's Street, Southampton, at 7.30 p.m.)

12 November. Society of Chemical Industry, Corrosion Group. Discussion of Practical Corrosion Problems of Industries of the South-West. "Corrosion-Resisting Metals for Marine Applications", by L. Kenworthy; "Protective Coatings", by W. E. Ballard; and "Plastic Coatings and Linings", by F. F. Jaray. (The Technical College, Plymouth, at 2.30 p.m. and 6.30 p.m.)

13 November. Institute of British Foundrymen, Bristol and West of England Branch. Foundry Regulations. Open discussion on papers presented by a panel of experts. (T. H. and J. Daniels, Ltd., Stroud, at 3.0 p.m.)

13 November. Institute of British Foundrymen, Newcastle Branch. "Dust Problems in Foundries", by W. H. White. (Neville Hall, Westgate Road, Newcastle-upon-Tyne, at 6.0 p.m.)

13 November. Institute of British Foundrymen, West Riding of Yorkshire Branch. "Moulding", by L. L. Allard. (The Technical College, Bradford, at 6.30 p.m.)

15 November. Institute of British Foundrymen, Birmingham Branch. "The Hardening of Moulds and Cores by the CO_2 Process", by Dr. D. V. Atterton. (James Watt Memorial Institute, Great Charles Street, Birmingham 3, at 7.15 p.m.)

16 November. Institute of British Foundrymen, East Anglian Section. "Gadgets". (The Central Hall, Public Library, Ipswich, at 7.30 p.m.)

[*Continued on p. 173*

A REVIEW OF DEVELOPMENTS IN THE MELTING, REFINING, AND CASTING OF COPPER * B9

By H. J. MILLER,† M.Sc., F.I.M.

SYNOPSIS : Reference is made to the revival of copper refining in Britain during the last twenty-five years, and developments in melting and casting practice—in particular, in methods of continuous casting—are described.

Introduction

OVER the last few years, many different and often unrelated factors have influenced developments in the melting, refining, and casting of copper. For an adequate review, it is necessary to consider the changes resulting from the development of new metal supplies, modifications in extraction practice, changes in customers' requirements arising from progress in fabrication methods, the introduction of entirely new methods of melting, and the recent work in applying continuous methods of casting. These are in addition to the basic items of developments in conventional refining and casting practice, and the contribution made by a better knowledge of the reactions involved.

The Industry in Britain

It is quite widely appreciated that the refining and casting of copper was conducted on a very small scale indeed in Britain in the years following the decline of the Welsh predominance in the middle of the last century until 1932. Over this long period smelting had fallen into complete decay, and the final operations of melting, refining, and casting were undertaken only in the case of non-standard shapes and compositions. Thus the country was dependent on imports for the whole of its requirements of high-conductivity tough-pitch copper wire-bars and of many of the other standard shapes, with the exception of a small production mainly obtained from scrap.

However, as a result of the opening up of the Rhodesian copper field and the collaboration of certain of the mining companies with fabricators in Britain, the production of fire-refined copper shapes by modern methods was established in this country at one plant in 1932 and at another in 1936, thus providing Great Britain once more with control over this phase of operations for some measure of its supplies. The equipment used comprised reverberatory furnaces of 150–200 tons capacity, having main-wheel casting facilities for horizontal wire-bars, and also, at a later date, side-casting equipment for shapes. These developments arose from a modification in the extraction procedure, which resulted from the fact that the particular ore bodies being worked were substantially free from impurities and precious metals, so that high-conductivity copper could be produced by fire-refining from the blister stage.

These plants have developed along certain lines to be considered later in this review, and have shown versatility in regard to meeting the customers' requirements. On the other hand, the restrictions in regard to form of raw material and the total volume of the copper industry in this country have limited the part which it has been possible to play in connection with some of the newer techniques. Indeed, many of these new techniques are unknown in this country, though there is no doubt that the influences which have brought about some of the changes overseas may in time extend here also. It is only by making a general review of all practices which appear to be of importance that one can form opinions on the probable lines of development.

Trend in Metal Supplies

During the last 25 years, a major factor in the copper industry has been the development of ore bodies relatively free from impurities and precious metals, so that the smelted product need not be subjected to the stringent treatment involved in electrolytic refining, by means of which both impurities and precious metals can be more or less completely eliminated. This has rendered possible the production of high-grade fire-refined copper and fire-refined high-conductivity copper. Products in the former group include the Braden copper from Chile, the M.T.D. copper from South Africa, the Chino copper and several other brands from many small properties in the U.S.A. and Canada. In the fire-refined high-conductivity group there are the Roan Antelope and Mufulira products under the brands British Copper Refiners (B.C.R.) and Enfield Rolling Mills (E.R.M.), and the Lake coppers from Michigan in the U.S.A.

However, detailed consideration of the primary treatment to be applied to ore bodies is outside the scope of this review. It is sufficient to say that practically every ore body has peculiar characteristics which demand special consideration. Where smelting methods are employed, the blister coppers which are obtained have their own distinctive compositions, and at this stage the influence of at least a dozen elements, present in amounts varying from traces to as much as 0·5%, must be considered. Depending on the results, either electrolytic refining or fire-refining only is adopted. Where wet-extraction processes are used in the treatment of the ores, again the individual impurities must be considered.

About 85% of the world's supply of primary copper is obtained as electrolytic copper and 15% as fire-refined; these proportions have remained fairly steady over a long period. Owing to the great predominance of electrolytic refining, it is only natural that most of the casting developments, considered below, have been made with electrolytic cathodes as the raw material.

In primary-metal production, the electrolytic refining stage has undergone many minor improvements which have helped in the production of extremely high-quality cathodes, the term " high quality " applying to both physical appearance and composition. The process itself has not undergone any radical changes, and indeed both the layout and the methods

* Presidential Address to the Liverpool Metallurgical Society, a society associated with the Institute of Metals.

† Engineering Manager, Metals Division, British Insulated Callender's Cables, Ltd., Prescot, Lancs.

employed in tank-house practice today are very similar to those of 40 years ago. Important advantages have attended the addition of colloids and of certain chemicals to the solutions, so as to obtain smooth, hard, and dense cathodes and to cause slimes to settle. Temperature control of the solution has been made more accurate, as this helps in suppressing slimes. Cathode washing has been made more thorough, thus giving cleaner products, free from contamination with sulphates. Above all, the technique for purifying solutions has been improved, and nowadays electrolytic-refining technologists appreciate just how far impurities should be permitted to build up in their solutions, particularly when working with anodes of a constant composition. As regards solution control, one of the most helpful methods developed is that of the preferential removal of nickel by means of the Pyne–Green cell, whose operation depends on the differences in concentration of nickel sulphate and copper sulphate in the top and bottom portions of the tanks. This has been particularly helpful when dealing with blister copper containing about 0·5% nickel and very little of other impurities which pass into solution.

As a result of the various changes in electrolytic tank-house practice, leading to the production of cathodes of extremely high quality, thought was given to alternative methods of melting and casting without going through a full refining cycle; the developments which have followed from these earlier studies are referred to in some detail later.

The impact of scrap-metal supplies is a serious one from many aspects. Most scrap can be used directly for making copper alloys, but with the ever-increasing quantities which are coming forward, it is necessary for larger amounts to pass through the hands of refiners. The problem scrap presents is quite complex because of the range of compositions. Some scrap can be rendered into fire-refined copper ingots for alloy production, but some must pass through an electrolytic-refining stage. At the customs smelters in U.S.A. and Europe, the general practice is to incorporate scrap and blister in making anodes. In the electrolysis of the latter, the problems of removing impurities are greater than in the case of a producing company, which operates on material of a very regular composition. Other plants prefer to treat the secondary copper anodes alone, in which case the anode contains 90–98% copper. With such material, the slime problem is mainly one of settling tin and lead, and the quantities of slimes are much greater than those with which primary-metal producers have to contend.

It is clear that all problems connected with the treatment of scrap have not been solved, and indeed intensive study of them may not pay because compositions are so variable, and hence the formulation of a standard practice is impossible.

To summarize the influence of trends in metal supplies, the outstanding features have been:

(1) The primary production of blister copper suitable for fire-refining into either high-grade ingots or high-conductivity shapes.

(2) The primary production of cathode copper, of extremely high purity, such that subsequent fire-refining may be omitted and the product merely melted for the purpose of casting into the required shapes.

(3) The recovery of copper from scrap material, either by fire-refining or by electrolytic refining.

Progress in Fabrication Practice

Looking back over a period of 25 years or so, it is possible to relate many of the major developments in refining and casting practice to demands made by fabricators. These fall under the three headings: quality, shapes, and sizes of castings, though in considering such changes a clear differentiation of the exact influence of each is impossible.

By far the most important product of copper refineries is the horizontal-cast wire-bar of 250–275 lb. weight. Both weight and shape are worthy of further consideration. This weight is specified because wire-rod mills can apparently handle such bars at minimum cost; the horizontal shape persists because refiners can cast it at maximum rate and consequent minimum expense. There have been arguments regarding this restriction on the weight of bar fabricated in copper rod-rolling mills, particularly as steel wire-rod mills have stepped up to the range of 400–700 lb., and modern aluminium wire-rod mills are now rolling 180–250-lb. bars.

Nevertheless the fact remains that none of the latest copper mills has employed heavier bars for routine wire-rod production,[1] though many mills roll heavier bars for special rod products. There have also been arguments concerning the merits of vertical casting and horizontal casting; in this connection it must be remembered that tough-pitch copper—alone amongst commercial metals—is in a condition which is most suitable for horizontal casting.

Thus, on balance, it is the consensus of opinion that horizontal-cast bars of 250–275 lb. weight will remain the established form of intermediate raw material for normal wire production.

One of the big steps forward in casting practice has been that of the development of the vertical-cast copper wire-bar. The conventional horizontal-cast wire-bar inevitably has a high oxygen content at the upper surface, and the fabricated section, strip, or wire possesses a concentrated oxide zone as a result. This is sometimes deleterious, particularly in respect of bending characteristics. Products obtained from vertical-cast bars are quite free from this type of segregation and are therefore superior. However, quite recently the scalping of the set surfaces of horizontal wire-bars would appear to have gained favour, because this is cheaper, and the product is a sufficiently good substitute. Nevertheless vertical-cast wire-bars have a definite field of use.

A further important development has been the production of oxygen-free high-conductivity (O.F.H.C.) copper, which was in the first place produced for special electrical purposes, but has achieved wider uses because of its superior properties, namely greater ductility, ability to be fused to glass, and freedom from attack by reducing gases at high temperatures. This development of a technique for producing oxygen-free high-conductivity copper represented a great step forward in a large number of ways. The fundamental principles of the gas–metal reactions which take place on casting came to be appreciated for the first time, while from the practical aspect the project involved the use of electric melting of high-purity cathodes under reducing-gas atmospheres and vertical casting of the molten metal into water-cooled moulds, thus bringing together the major developments of the last 25 years.

Another type of copper, the use of which has advanced extremely rapidly, is phosphorus-deoxidized metal. This is particularly suitable for the fabrication of certain products because of the ease with which oxide scale, formed during preheating, is shed during the working process. Phosphorus-deoxidized copper must also be cast by vertical methods, the shapes being limited to cakes and billets; this type of copper is suitable for mechanical purposes only, as its electrical conductivity falls below the minimum required for electrical applications.

Thus, from the aspect of quality, vertical casting has gained favour quite incidentally. Under the heading of shapes and sizes, as required by the fabricators, the outstanding feature has again been the demand for vertical-cast shapes.

Over the last 25 years or so, the copper-tube industry has undergone an approximately fourfold expansion of size, and there has been a correspondingly increased demand for billets for either extrusion or rotary piercing. The sizes range from about 5 to 8 in. for extrusion, and about 2·5 to 5 in. for piercing. These two fabrication methods are in strict competition, but from the caster's point of view the sizes for piercing are definitely small, and they therefore reduce the casting output and are more costly. There is reason to think that in future plant schemes larger extrusion billets may be demanded, particularly if the bull-block drawing of tubes is taken up with enthusiasm. For the production of copper strip and sheet, the use of flat cast cakes has now virtually disappeared, and the early type of wedge cake cast in solid moulds is also rapidly being superseded by vertical-cast cakes.

Such features as the application of wide-strip rolling methods, the extensive mechanization of mills, and the use of high rolling speeds, have required the provision of heavy-weight coils on economic grounds, and altogether strip-rolling practice has virtually undergone a revolution. Producers of cast products have had to keep pace with the new demands which today in the most modern cold-rolling mills require the stock material to have a weight in excess of 100 lb./in. width. Although welding may be adopted for giving long coils of copper, it is not as suitable as when dealing with steel or brass, and indeed perhaps the method has not as yet been successfully applied on a full scale. It is preferred therefore to begin with heavy-weight castings. Whereas the weight of cake made 25 years ago was seldom more than 300 lb., it has been stepped up to 500, 1000, and 2000 lb., and today cakes of 3000 lb. are in regular production at U.S.A. refineries for rolling ultimately into strip.[2] Such developments are still comparatively new in the U.S.A., but it is believed that sooner or later the demand for extremely heavy vertical-cast cakes will extend to this country.

Developments in Refining and Casting Practice

This aspect of the subject is possibly best considered under two distinct headings (*a*) refining practice and (*b*) casting practice, attention being confined to plants equipped with the conventional reverberatory and similar furnaces.

(a) *Refining Practice*

The reverberatory refining furnace underwent its greatest development in the period from 1890 to 1910, immediately after the introduction of gas and fuel-oil for firing purposes. Since then, progress has depended on a series of minor refinements, rather than on any spectacular advance, and amongst these may be mentioned burner designs for gas, fuel-oil, and pulverized-coal firing, furnace and roof structures and refractories, water-cooled inserts, recuperation by preheating of air, design of waste-heat boilers, and methods of charging. On the operating side, the cycle has not undergone radical changes, but in some cases special slagging procedures have been introduced to remove specific impurities, though it is only in rare instances that such practices are employed, the most important being for the removal of arsenic and antimony.[3, 4]

Furnace capacities mostly range from 150 to 400 tons when used for casting wire-bars only, 100–250 tons for casting wire-bars and side-cast shapes, and 40–100 tons (in a few cases up to 200 tons) for the direct casting of shapes. The refining cycle is conventionally on a 24-hour basis, to include charging, melting, oxidizing, skimming, poling, and casting, and in the case of reverberatory furnaces there have not been any radical departures from this.

A notable development of the last 25 years, particularly in Europe, has been the adoption of rotary melting furnaces of capacities from about 2 tons up to 20 tons, though some larger units have also been installed. The principal advantage of rotary designs is the considerable reduction in time required for completion of the cycle of operations, this being from about one-eighth to one-third of that necessary in the case of reverberatory practice. It is to be noted, however, that the rotary furnace has not entirely supplanted the small reverberatory furnace, and probably on the whole there is little difference in operating costs and efficiency. Both the small reverberatory and the rotary furnaces are of particular advantage for the casting of special shapes, which may range from the usual sizes of billets or cakes to the very large castings needed for fabrication into heavy sheet for locomotive fireboxes and chemical vessels.

(b) *Casting Practice*

Casting practice as adopted in the conventional type of refining plant has undergone far more changes, as will have been apparent from earlier comments. The Walker and Clark types of casting wheel—as developed at the beginning of the century, when the size of reverberatory furnaces was greatly increased—remain the essential unit for wire-bar casting. They have been adapted for billet and cake casting, using both solid and water-cooled moulds, at a few plants, though the majority of shapes are cast either by a side-casting technique or from special furnaces.

In wire-bar casting, relatively recent achievements are the use of the five-bar mould on the Walker wheel and the double-mould pouring of six bars at a time on the Clark wheel. These methods give a speed of casting which is of the order of 60 tons/hr. A feature of recent layouts is the provision of multiple launders so that the copper may be run from an individual furnace to any available wheel, thus providing flexibility in use of furnaces and casting wheels.

The casting of wedge cakes of 300–500 lb. on Clark wheels is relatively old, and the methods of handling are essentially the same as for wire-bars. The later introduction of the water-cooled mould for producing cast cakes of greater length and more accurate dimensions has necessitated a departure from the normal main-wheel routine. Main wheels have been equipped in only a few instances to take water-cooled moulds; one reason is that the speed which can be attained in casting, even when double pouring with the aid of two ladles, does not match the speed at which it is necessary to pour from reverberatory furnaces. Instead, the main method of casting billets and cakes has been by "side-casting", in which covered ladles of 5 tons capacity are used to transfer the metal from the furnace to a convenient casting position.

The history of the water-cooled mould is of considerable interest. Junghans, in the early 1920s, developed a water-cooled mould having a comparatively thin wall of copper, which was most successful with brass but gave unsatisfactory results with copper, chiefly because of distortion. Towards the end of the 1920s, the American Metal Company perfected a water-cooled type of mould of heavy section, made by machining a number of holes in solid copper shapes and suitably cross-connecting these so as to provide vertical water passages.[5] The Amco type of mould is the most common one now employed for the casting of the copper shapes. Interest later returned to the lighter type of construction of the Junghans

mould, and, by the incorporation of suitable expansion devices, it was found possible to overcome the earlier shortcomings. Moulds of this type are in use at several refineries for the casting of square wire-bars, round billets, and small-section cakes; the mould material can be either copper or steel, and various advantages are claimed for these two materials by the firms using such designs of mould.[6]

The two types of water-cooled mould, i.e. that machined from the solid shape and the fabricated type, are always constructed for bottom dumping of the cast shapes, in contrast to the practice in casting copper alloy slabs. The bottom plates are almost always of copper, though graphite insert pieces are sometimes used. The wear on the bottom plates due to the impact of the stream of molten metal is quite serious, and to avoid it and also the splash effect which gives rise to defective surfaces, pelican ladles are often used to break the stream of molten metal. An extra operator is naturally required to insert and withdraw these ladles.

Moulds in current use for casting billets and cakes are up to 60 in. long, but quite clearly casting difficulties increase with the length because of the splash effects, even if for no more serious reason. As a means of avoiding many of the problems introduced in the casting of long billets, some refiners have turned their attention to continuous-casting methods, as considered later.

Quite clearly bottom dumping of long billets and cakes raises a problem in respect to height, and the provision of a deep pit for the longest shapes is a matter of considerable expense. In one of the latest U.S. plants, two reverberatory furnaces, each of 200 tons capacity, have been built roughly at right angles to each other, so as to make use of one casting wheel of a special type suitable for long cakes weighing up to 3000 lb.; the two furnaces cast on different shifts into the one wheel provided.[2] Obviously such arrangements are suitable only when large quantities of a given product are required.

Side casting provides considerable flexibility, even though it introduces a further stage, involving the transfer of metal in portable holding furnaces of 5 tons capacity, adjustment of temperature and pitch, and casting on an independent wheel or by other means; alternatively, the metal is deoxidized with phosphorus instead of being brought to pitch. In some cases, instead of casting from the holding furnaces, the metal is transferred to another furnace at a fixed location.

In one installation, a 15-ton pouring furnace is used in conjunction with a wheel of 27 ft. dia. The 15-ton furnace, fed by a battery of 5-ton holding furnaces, operates on a steady casting cycle with an output as high as 150 tons/8-hr. shift. A total crew of 7 men is employed for the operations, two men pouring from the two independent ladles provided, each of which, in the case of billet casting, has two lips.[6]

The more usual side-casting procedure is to pour from the 5-ton holding furnaces either into moulds mounted on a much smaller wheel, say 12 ft. in dia., or direct from a crane to moulds which are mounted in a row.[7]

New Techniques in Melting

The restrictions imposed by reverberatory melting practice will be clearly apparent from the foregoing discussion, and for this reason much interest has been taken in alternative melting methods, particularly by electric arc and electric induction.

Consequent upon the improvements in quality and composition of cathodes resulting from good tank-house practice, the Ontario Refining Company in 1936 installed an arc furnace for melting cathodes continuously, without their having to undergo the time-honoured and long-protracted process of oxidizing and poling so as to obtain the correct balance of oxygen, hydrogen, and sulphur to give tough-pitch metal.[8, 9] The unit, which has a molten-metal capacity of 30 tons, is operated continuously at a charging and pouring rate of up to 10 tons/hr., depending on the type of product being cast. It is of interest to recall that the possibilities of this technique had been discussed as early as 1914.[10]

A feature of the layout of the O.R.C. plant is the use of a comparatively long launder leading to an induction holding furnace at the casting wheel. The launder is provided with refractory covers having resistance inserts, so as to maintain the temperature of the metal. Many other refinements are provided, including the use of immersion pyrometers which facilitate automatic control of the current input to the furnace, and the further control over condition provided by the induction holding furnace.

The molten metal from arc furnaces is found to have an oxygen content of the order of 0·01–0·03%, and by careful control of the ventilating effect in the furnace this range can be narrowed so that, allowing for the slight pick-up of oxygen which always occurs on pouring molten metal via launders and ladles, the cast products have extremely constant oxygen contents of 0·025–0·04%.

The main advantages of continuous melting and casting practice are the entire absence of slags, economical working, constancy of composition, and the fact that molten metal is available for 24 hr. a day at a steady rate of 10 tons/hr. This quantity compares with the somewhat inconvenient amount of 150–300 tons and upwards which must be poured in about 6 hr. with normal fire-refining furnaces. Thus, the installation is of particular advantage for the casting of vertical shapes.

In 1942 the American Metal Company finally succeeded in obtaining satisfactory results from an electric induction furnace —the Summey furnace—which had been built as early as 1931 or 1932, but which had not then given success owing to the failure of the refractories of the inductor units.[11] The principle in this project is the melting and casting of high-purity cathodes under controlled gas atmospheres so that there is a complete avoidance of oxygen pick-up. The current experience with this induction furnace is that it gives a continuous supply of molten metal at a rate of about 10 tons/hr. for a power consumption of 250 kWh./ton. In the interim period, 1932–42, the American Metal Company produced their oxygen-free high-conductivity copper by flowing tough-pitch metal through hot charcoal,[12] but since 1942 all this type of copper has been obtained from metal melted in the Summey induction furnace.

Certain disadvantages of the Summey furnace, particularly the inability to remove and replace defective inductor units while the furnace is in operation, have led to the development of the Scomet electric induction furnace. By simple rotation of this latter furnace so that the faulty inductor is brought above the metal line, it is possible to replace the inductor speedily. Thus, for new installations to produce oxygen-free high-conductivity copper, the Scomet induction furnace is recommended. Incidentally, Scomet furnaces having an output of about 4 tons/hr., have achieved considerable reputation for the melting of brass.

There are thus now available two distinct commercial methods for the melting of cathodes, and the question of the relative advantages of the arc and induction furnaces is somewhat difficult to answer at this stage of development. Both methods would appear to be applicable for use with a supply of

good-quality cathodes only; however, arc furnaces have been used for melting down scrap for the production of anodes,[13] and they have also been suggested for the melting of high-grade blister copper for certain other products. It would appear that the cost of installing and operating the induction type of furnace is slightly greater, and with this type it is essential to maintain the metal in a completely oxygen-free condition to avoid attack of the refractory channels. The provision of inert-gas atmospheres is an expense which is not justified in the production of deoxidized copper shapes for most commercial purposes, though this is essential for oxygen-free metal. The induction furnace offers advantages in respect of its quieter working and suitability for commercial power supplies, whereas the arc furnace has suffered power troubles at some plants.

It is most notable that these newer techniques have been applied in practically all the most recent plant installations, though it must be made clear that in general they have not replaced reverberatory-furnace practice; they have provided additional capacity or permitted the production of new products. Announcements of arc-furnace installations have been made by Canadian Copper Refiners, Ltd., Montreal; American Smelting and Refining Company, Baltimore [14]; Kennecott Copper Corporation, Utah [13]; and Rhodesian Copper Refiners, Ltd., Rhodesia. These units have come into operation since 1950, and the rates of casting attained vary from 5 to 18 tons/hr. The former figure is appropriate when casting small billets; the latter has been obtained when casting heavy cakes and also horizontal wire-bars.

The Development of New Methods of Casting

The application of continuous-casting methods to the production of copper shapes is now receiving considerable attention, though the developments lag considerably behind those reached in the continuous casting of copper alloys, particularly the brasses. This is accounted for by the peculiar metallurgical characteristics of copper.

Of the continuous processes it is known that the following are at present being applied in some degree:

(*a*) The Junghans–Rossi process.
(*b*) The Inco or Welblund–Benard process.
(*c*) The Asarco process.
(*d*) Semi-continuous processes based on the Alcoa and V.L.W. processes.

The great virtue of all continuous-casting methods lies in the greater soundness and longer products which may be obtained, namely up to the limit of operation of the mechanically traversing saws, say 10 ft. This fits in admirably with the demand of fabricators for long, heavy slabs, as previously discussed.

(a) *The Junghans–Rossi Process*

This process originated in the period 1927–32 at the plant of Wieland Werke, Germany, for the casting of brass, and was tried experimentally for copper at the plant of the Scovill Manufacturing Company, some time after the installation of the first continuous-casting machine in 1940. It was not until about 1948, however, that the installation of a Junghans–Rossi machine for the casting of copper was undertaken by the American Metal Company, and this machine has since been in successful use in conjunction with the Company's O.F.H.C. plant.[15] The unit is fed with metal from a Scomet holding furnace, supplied from the Summey induction furnace. The extensive series of launders and the upper part of the casting unit are completely enclosed, and a specially prepared reducing-gas atmosphere is circulated at a slight pressure. Considerable work has been undertaken to determine the best type of mould and mould dressing—namely carbonaceous material deposited by burning a smoky flame around the metal stream—to achieve cast products of excellent surface, practically free from the folds such as are usually present on brass castings made on these machines.

The Junghans–Rossi machine is used in campaigns for the casting of either round billets of dimensions up to 10 in. dia. or cakes of dimensions up to 26 × 4 in. section, and the speeds of casting range from 12 to 20 in./min., providing an output of about 5–6 tons/hr.

Although the casting of O.F.H.C. copper is quite successful, difficulties have been encountered in the case of tough-pitch metal owing to cracking of the cast shapes. The process might be improved to the point at which the casting of tough-pitch metal could be undertaken, but it must be borne in mind that the whole process is so operated that the supply of molten tough-pitch copper from batch-operated furnaces would be rather unwieldy and no doubt uneconomic. Continuity of supply of molten metal is of fundamental importance, and thus a continuous-melting process based on the use of cathode copper appears an essential prerequisite.

(b) *The Inco or Welblund–Benard Process*

This process was developed at the O.R.C. plant of the International Nickel Company in about 1939, but it was not brought into successful use on a continuous basis until 1942, when it was installed at the Carteret plant of the American Metal Company, in conjunction with the O.F.H.C. continuous-melting unit. It has been employed solely for the casting of 4-in.-square V.C. wire-bars and billets of approximately similar section, and the casting rate is about 10–12 in./min., corresponding to about 2 tons/hr.[16]

The machine has a split mould, the two halves of which are vibrated together at a high speed and low amplitude with the object of reducing frictional effects between the mould and the solidified shape. The two halves of the mould are constructed from heavy copper sections, suitably drilled for water-cooling and chromium-plated on the working surfaces.

Owing to its comparatively small output, the economics of continuous casting with this machine are possibly not attractive; at any rate there seems to be no tendency to develop this type.

(c) *The Asarco Process*

This process was born out of two distinct developments, namely that due to Eldred, who played an active part in the casting of copper shapes about 1934, and the work of Poland and Lindner of the American Smelting and Refining Company, which began about the same time. The resultant Asarco process was ultimately brought into production on a fairly large scale in 1939 for the casting of phosphorus-deoxidized copper billets of 3 in. dia.[17]

The essential feature of the process is that molten metal, which is held in a resistance-heated container, is permitted to flow through an exit die at the lowest position of the container. The die is of graphite, and below it there is a water-cooling chamber. Withdrawal rolls control the speed of removal of the solidified shape through the die. In the case of 3-in.-dia. billets, this speed is of the order of 6–8 in./min., corresponding to a production of about 0·5 ton/hr. The equipment includes a flying saw to cut the cast products to the necessary lengths, and there is a suitable receiver and conveyor in the basement. The equipment is thus comparatively simple, and the process

operates for long periods without attention on the part of operators. In fact, personnel are required only to maintain sufficient metal in the holding furnace, to manipulate the flying saws, and to deal with the cast products. A battery of machines can thus be effectively operated by a small crew. The necessity of providing separate melting facilities for the copper provides the major practical disadvantage of this process.

The procedure was worked out for phosphorus-deoxidized copper and has not been applied to tough-pitch metal, presumably because of difficulty in maintaining the pitch. The process has not been adapted for other types of copper or for alternative sizes and shapes, possibly because it is not economically attractive on account of the comparatively slow rate of operation. However, the Asarco principle proves very suitable and economical for small sections, and consequently all the later developments in connection with the process have been centred on the casting of small-dia. rods, tubes, and other shapes in copper–tin and other alloys.[18]

(d) *Semi-Continuous Processes*

The latest developments in the casting of copper and of the copper alloys are associated with various modifications of the semi-continuous process based on the Alcoa or V.L.W. methods. This interest is no doubt related directly to the comparatively simple plant which is required and to the fact that a large number of products can be cast in a single drop. While the essentially simple principle of the machines as developed for aluminium have been preserved, somewhat more complicated arrangements have had to be made for the supply of the molten metal in a suitable condition. The lubrication of the mould also raises a difficulty.

However, sufficient preliminary work has already been undertaken in Europe with phosphorus-deoxidized copper to indicate that this method holds considerable promise. Whether it will be competitive with other methods remains to be proved, and indeed as yet there has not been enough work carried out to justify an expression of opinion.

Gas Reactions in Refining

The attainment of the tough-pitch condition is bound up with gas solubilities and reactions, but only within the last 25 years have definite systematic studies been made of the subject. The elements playing a part in the process are oxygen, hydrogen, sulphur, and carbon.

It has long been known that the solubility of hydrogen increases with temperature in both the solid and liquid states, with a sharp change at the melting point. Furthermore, Allen and Hewitt [19] showed that the solubility of hydrogen in molten copper varies greatly with the amount of oxygen present, being much higher in metal having a low oxygen content. They also showed that the fundamental reaction in the production of tough-pitch metal is the evolution of the excess hydrogen at the solidification point and its reaction with part of the oxygen present to form steam, which is insoluble and thereby gives a great expansion effect to the solidifying metal. Thus, a balance of hydrogen and oxygen contents is considered to be the important requirement, and when this is out of balance the metal corresponds to either the underpoled or the overpoled condition. The amount of hydrogen required for the reaction is extremely small, so much so that it can always be derived from the moisture in the furnace atmosphere.

Although the oxygen–hydrogen reaction is the main one, much suspicion has always been attached by practical refiners to sulphur, especially as this can be picked up at a late stage, namely from the furnace gases while the refined metal is being held for casting. Thus, a subsidiary reaction occurs between minute amounts of sulphur and oxygen, so upsetting the pitch. The influence of sulphur and carbon has recently been investigated, and confirmation has been obtained of the sulphur–oxygen reaction. Carbon is of importance under certain conditions only, namely with metal raised to an abnormally high temperature.

Theoretical studies on the influence of gases in the refining and casting of copper have been of much help to refiners engaged in practising the time-honoured art which is involved in the normal refining process; furthermore, they have indirectly facilitated the development of alternative and improved methods.

Conclusion

In this review it has been possible to consider only some of the more outstanding features in the story relating to recent developments in the melting, refining, and casting of copper. A major aim has been to indicate the large number of important factors which have been involved, and their interrelation. An implicit conclusion is that there has been close collaboration between those involved in theoretical developments and those concerned with the practical problems of production. As a result of this collaboration, many important technological advances have been made, and indeed the copper industry has been in the forefront in many interesting metallurgical-engineering developments.

Acknowledgement

The author desires to express appreciation to British Insulated Callender's Cables, Ltd., for permission to publish this paper.

REFERENCES

1. ——, *Metal Ind.*, 1953, **82**, 83, 101.
2. C. D. Pearce, *J. Metals*, 1954, **6**, (5), 512.
3. C. T. Eddy, *Trans. Amer. Inst. Min. Met. Eng.*, 1931, **96**, 104.
4. W. J. Hillenbrand, R. K. Poull, and H. C. Kenny, *ibid.*, 1933, **106**, 483.
5. American Metal Company, Brit. Patent No. **348,333**.
6. "Non-Ferrous Heavy-Metal Fabrication in U.S.A." (O.E.E.C. Report of Technical Assistance Mission No. 79), pp. 40, 28. **1954**: Paris (Organization for European Economic Co-operation).
7. H. J. Miller, *Inst. Min. Met.: Symposium on Refining of Non-Ferrous Metals*, **1950**, 145.
8. R. H. Waddington and J. C. Bischoff, *Trans. Canad. Inst. Min. Met.*, 1946, **49**, 199.
9. R. H. Waddington, *J. Inst. Metals*, 1948–49, **75**, 311.
10. D. A. Lyon and R. M. Keeney, *Trans. Amer. Inst. Min. Eng.*, 1914, **49**, 724.
11. R. H. Bauld, *Inst. Min. Met.: Symposium on Refining of Non-Ferrous Metals*, **1950**, 185.
12. E. F. Cone, *Metals and Alloys*, 1937, **8**, (2), 33.
13. H. A. Shaw and H. G. G. Whitton, *Trans. Amer. Inst. Met. Min Eng.*, 1953, **197**, 197.
14. P. R. Drummond, *ibid.*, 1951, **191**, 468.
15. D. I. Brown, *Iron Age*, 1951, **168**, (9), 62.
16. T. W. Lippert, *ibid.*, 1944, **153**, (8), 48.
17. T. W. Lippert, *ibid.*, 1940, **145**, (14), 31.
18. J. S. Smart, Jr., and A. A. Smith, Jr., *ibid.*, 1948, **162**, (9), 72.
19. N. P. Allen and T. Hewitt, *J. Inst. Metals*, 1933, **51**, 257.

THERMODYNAMICS OF ALLOYS

By JOHN LUMSDEN, B.Sc.

(Research Department, Imperial Smelting Corporation, Ltd.)

Institute of Metals Monograph and Report Series, No. 11 *Cloth,* 390 *pp. with* 110 *illustrations*

Price 35s. or $5-50 post free. (Members, one copy at 17s. 6d. or $3.00 post free.)

This monograph deals with the application of thermodynamics to the quantitative study of metals and alloys. The fundamental theory of the subject is presented first, and is followed by some illustrative calculations on pure metals. Then the theory of solutions is developed and exemplified by calculations on solid and liquid alloys. Emphasis is laid on the usefulness of thermodynamics for the accurate correlation of various equilibrium properties. Attention is particularly directed to the information that can be deduced from phase boundaries. Detailed calculations are presented on some typical systems for which measurements of vapour pressures, electrode potentials and heats of mixing are available; these results are combined with a study of liquidus, solidus and solid-solubility curves to derive the activities of both components in the liquid and solid phases. It is shown how a free-energy equation for a system, deduced from a suitable set of accurate experimental measurements, furnishes a reliable basis for calculating other equilibrium properties. To assist in numerical calculations, tables of functions that continually recur in thermodynamic problems are provided.

Elementary statistical mechanics is introduced for calculating the entropy of gases and for interpreting the form of free-energy curves in solid and liquid alloys. A critical study is made of the extent to which liquid alloys behave as "regular solutions."

THE INSTITUTE OF METALS : 4 Grosvenor Gardens, London, S.W.1

THE STRUCTURE OF METALS AND ALLOYS

REVISED EDITION

by W. HUME-ROTHERY and G. V. RAYNOR

Institute of Metals Monograph and Report Series No. 1. *Cloth, 370 pp. and 8 plates.*

Price 35s. or $5.50, post free. (Members, one copy at 17s. 6d. or $3.00, post free.)

This well-known book by Dr. W. Hume-Rothery was first published in 1936, when it achieved an immediate success, and has since been reprinted seven times. Most of the principles outlined in 1936 have stood the test of time, but the tremendous output of research on the structure of metals and alloys has led to a demand for a thorough revision, and a new edition has now been written in collaboration with Professor G. V. Raynor.

The whole text has been revised and brought up to date, with considerable expansion of the parts dealing with solid solutions and intermediate phases in alloys. Completely new sections have been written on ternary alloys and on alloys of iron, whilst the part dealing with imperfections in crystals has been greatly extended and now includes a comprehensive account of the ideas of dislocation theory.

The description throughout has been kept at an elementary level, and can be understood without a knowledge of higher mathematics or of crystallographic notations. In this form the book should be invaluable to all those who, in the widest sense of the term, call themselves students of metallurgy, and it should also be of great value to physicists, chemists, and engineers.

Obtainable through booksellers or from :

THE INSTITUTE OF METALS, 4 GROSVENOR GARDENS, LONDON, S.W.1

Continued from p. 166]

17 November. Institute of British Foundrymen, London Branch. "Some Foundry Problems", by G. Rogers. (Waldorf Hotel, Aldwych, London, W.C.1, at 7.30 p.m.)

17 and 18 November. Iron and Steel Institute. Autumn General Meeting. (4 Grosvenor Gardens, London, S.W.1, at 9.45 a.m. and 2.30 p.m.)

18 November. Institution of Mining and Metallurgy. General meeting. (Geological Society, Burlington House, Piccadilly, London, W.1, at 5.0 p.m.)

19 November. West of Scotland Iron and Steel Institute. "Direct-Reading Spectrographic Analysis of Ferrous Metals, with Special Reference to the Use of the Quantometer", by A. Argyle. (Institute of Engineers and Shipbuilders in Scotland, 39 Elmbank Crescent, Glasgow, C.2, at 6.45 p.m.)

24 November. Society of Chemical Industry, Dublin Section. "Metallic Corrosion and Its Control", by Dr. W. H. J. Vernon. (Dept. of Chemistry, University College, Dublin, at 7.45 p.m.)

26 November. Physical Society. Seventh Rutherford Lecture: "The Organization of Scientific Discovery", by Professor P. M. S. Blackett. (Lecture Theatre, The Science Museum, Exhibition Road, London, S.W.7, at 5.0 p.m.)

30 November. Society of Chemical Industry. Second Robert Horne Memorial Lecture: "Metallurgical Progress and the Chemical Industry", by Dr. Maurice Cook. (Chemistry Lecture Theatre, University College, Swansea, at 6.30 p.m.)

1 December. Royal Institute of Chemistry, London Section. "Germanium: Its Extraction and Uses", by A. R. Powell. (South West Essex Technical College, Forest Road, Walthamstow, E.17, at 7.0 p.m.)

1 and 2 December. Iron and Steel Institute. Symposium on Powder Metallurgy. (Church House, Westminster, S.W.1, at 9.30 a.m. and 2.0 p.m.) For details, see pp. 162–3 of the Oct. issue of the *Bulletin*.

APPOINTMENTS VACANT

BRITISH STEEL CASTINGS RESEARCH ASSOCIATION RESEARCH BURSARY. Applications are invited from suitably qualified graduates for a bursary provided by the British Steel Castings Research Association, tenable in the Department of Metallurgy, University of Cambridge. The successful applicant would be required to undertake research, which could lead to the Ph.D. degree, into the causes and prevention of intergranular fracture in steel castings. The bursary is similar in amount to current D.S.I.R. maintenance allowances and is tenable for two years, with renewal for a third year.

Applications, giving full particulars, should be addressed directly to Dr. T. P. Hoar, Department of Metallurgy, Pembroke Street, Cambridge.

METALLURGICAL ASSISTANT required with minimum qualifications H.N.C. (Metallurgy) and must have completed National Service or not liable. Applicants should preferably have had experience of metallography of ferrous and non-ferrous metals, particularly in heat-treated steels. Write to Joseph Lucas (G.T.E.), Ltd., Victor Works, Bowring Park Road, Liverpool 14.

METALLURGICAL ASSISTANT required for interesting position in our laboratory at Shaftmoor Lane Works. Applicants should preferably have had industrial experience. This appointment is pensionable and offers good prospects to a person with initiative and technical ability. Applications should be sent to Personnel Manager, Joseph Lucas (Gas Turbine Equipment), Ltd., Shaftmoor Lane, Hall Green, Birmingham 28.

METALLURGICAL CHEMIST. Competent young analyst with knowledge of ferrous and non-ferrous analysis and the use of modern techniques required by organization near Leicester. Excellent opportunity for carrying out interesting work connected with a variety of research and development projects. The position is permanent and progressive. Some knowledge of plating an advantage. Should have completed National Service. Superannuation scheme in operation. Send full details, including salary required to Box No. 376, Institute of Metals, 4 Grosvenor Gardens, London, S.W.1.

METALLURGICAL RESEARCH INVESTIGATOR. A vacancy exists for a graduate Metallurgist to undertake fundamental research into the properties of bearing materials. The successful applicant, in addition to possessing suitable metallurgical qualifications, must have an aptitude for fundamental thinking and a flair for original research. The Company has good facilities in the way of apparatus and assistance is available on statistical design and analysis. There are very good prospects for the right man and a good starting salary is offered. Apply: Personnel Manager, Glacier Metal Co., Ltd., Ealing Road, Alperton, Middx.

METALLURGIST required, having completed National Service. Minimum qualification A.I.M. Should preferably have experience in Metallography of ferrous and non-ferrous aircraft materials, in particular heat-treated steels. This appointment is pensionable and offers good prospects to an individual with initiative and technical ability. Applications should be sent to Personnel Manager, Joseph Lucas (Gas Turbine Equipment), Ltd., Shaftmoor Lane, Hall Green, Birmingham 28.

METALLURGISTS, with degree or equivalent qualifications, wanted for research by Midland company manufacturing sintered alloys. Age 23 to 25. Salary according to age and experience. Reply to Box No. 375, Institute of Metals, 4 Grosvenor Gardens, London, S.W.1.

RESEARCH METALLURGIST with good degree and experience is required by organization near Leicester to undertake work on problems associated with machining and forming of ferrous and non-ferrous materials. Knowledge of the cold working of metals would be an advantage. Surroundings are pleasant, and the successful candidate will be working in interesting fields which offer wide scope. Permanent progressive position. F.S.S.U. in operation. Full details including age, experience, qualifications, and salary required to Box No. 378, Institute of Metals, 4 Grosvenor Gardens, London, S.W.1.